UNIVERSITI SAINS MALAYSIA

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(SCHOOL OF HEALTH SCIENCES, UNIVERSITI SAINS MALAYSIA)

Restoration of Engraved Marks on Aluminium Surfaces by Etching Technique

Dissertation submitted in partial fulfillment for the Degree of Bachelor of Science (Health) in Forensic Science

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2007

CERTIFICATE

This is to certify that the dissertation entitled

Restoration of Engraved Marks on Aluminium Surfaces by Etching Technique

is the bonafide record of research work done by

Mr. Mohamad Izhar bin Mohd Baharum

during the period of 17th December 2006 to 2nd May 2007 under my supervision.

ACKNOWLEDGEMENTS

First and foremost, I would like to thank God the Almighty for giving me strength, ideas and patience to complete my final year research project.

I would like to thank my supervisor, P. M. Dr. R. Kuppuswamy for his assistance, help and advice in the planning and execution of this research project. My greatest appreciation to ASP Azari bin Abd. Rahman and Encik Ghadafi from Maktab Pegawai Kanan PDRM for their consultation and advice in completing this research. My grateful thanks also extend to Mr Ah Koon and his staff from Rex Trading Kota Bharu, Puan Hafizah Harun, Encik Rosliza Haron, Puan Rosniah Yusoff, Encik Wan Mohd Sahnusi and Encik Zulkhairi Othman for their great assistance and co-operation in completing this challenging work.

I also would like to express my gratitude to all PPSK lecturers, science officers and laboratory staff, who contributed directly or indirectly for the completion of this research project. Special thanks are due to my family members whose support helped me a lot in completing this work. Last but not the least, I would like to thank all my friends for giving me moral support and also assisting me in this research project.

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ABSTRACT

Restoration of erased engraved marks is considered difficult compared to the restoration of stamped marks, as the deformation occurring to the metal due to the engraving is minimal. Hence, a series of experiment were conducted to determine the sensitivity and efficacy of various selected reagents to restore erased engraved marks on aluminium surfaces, as this metal has been widely use in motorcycle engines and firearms.

The experiments consisted of preparing several aluminium plates and engraving them using a computer controlled engraving machine, *Gravograph*. The marks were erased to different levels down to the depth of the engraving. Some selected reagents were applied on the erased plates by swabbing etching technique to restore the erased engraved marks. Two metallographic reagents: (1) 60% hydrochloric acid (HCl) and 40% sodium hydroxide (NaOH) and (2) acidified ferric chloride solution consisting of 25 g ferric chloride, 25 ml hydrochloric acid and 1000 ml of water were determined to be sensitive, as both restored marks up to a level of 0.04 mm below the depth of engraving. However, the above reagent (1) was considered to be the most sensitive one, as the marks recovered by it were more distinct with no difficulty to viewing.

Experiments were also performed by erasing the engraved aluminium plates to different levels below the depth of engraving and over-engraved with different marks.

The original marks that had been erased were restored using 60% hydrochloric acid (HCl) and 40% sodium hydroxide (NaOH). However, the depth of restoration decreased from the original 0.04 mm (without over-engraving) to 0.03 mm.

INTRODUCTION

Restoration of erased identification mark has become one of the major concerns in forensic science practice. These marks may be either serial number on engine and chassis of a vehicle, jewelry or on firearms. Serial numbers may consist of numerals, letters, symbols or combination of three of them. Markings such as serial numbers, letters, codes and labels are applied to distinguish various items and to sign items in commercial uses (Katterwe H., 1994).

Serial numbers are regularly removed from the items in order to hide their true identity, which is common in criminal cases. The reasons for the removal are varied and include:

- To hide the origin of the item used in the commission of a crime, such as removing the number from a firearm used in a murder;
- The perpetration of fraud, such as portraying an item to be of a different value when making an insurance claim;
- To prevent positive identification of a stolen property.

Serial numbers can be applied to objects by way of adhesive labels, or by directly impressing on to the actual object. Generally, direct application on to the object is used when the item is composed of metals and labels are used on plastic items.

According to the statistics made available by Royal Malaysian Police, there were approximately 60,000 vehicle theft cases in Malaysia between January and September 2006. This does not include those which were not reported (http://www.rmp.gov.my/rmp03/statindeks2006.htm). Among those cases, motorcycle theft contributes the highest with 47,163 cases followed by car theft and van/lorry theft with 8,268 and 4,666 each. This statistics shows that vehicle theft has been a major problem in Malaysia. The stolen vehicle may be sold in whole to the neighboring country or the parts will be detached and sold as spare parts. In order to be sold, the serial numbers on the vehicle, either engine or chassis number will be erased or obliterated. Similarly, the serial number of a firearm also plays a very important role in tracing the origin of a gun recovered from a crime scene. Thus, in crime involving vehicle theft or crime involving gun, where the marks are erased or obliterated, it becomes necessary to restore the original marks. At present various restoration techniques to retrieve the erased original numbers are available. These methods vary according to different metal surfaces.

In this project work, the restoration of engraved marks on aluminium surfaces is considered. Engraved marks are small and shallow incised marking. The underlying metal is not seriously disturbed, thus erasure of this marking is usually effective and restoration is often difficult. Aluminium has been chosen as it widely used nowadays in motorcycle engines. Often serial numbers on the engine of a motorcycle are erased to hide its original identity. Gun such as a Ruger P-85 pistol frame is made from aluminium; on which surface the identification number can be found on. Besides, car manufacturer such as Audi has begun to use aluminium alloy in producing car chassis.

APPLICATION METHODS OF IDENTIFICATION MARKS

Identification marks can be applied in a variety of ways depending upon the substrate to be marked and also the environment under which the number will be used in. The major methods include the following (Katterwe H., 2006):

- ***Die stamping.*** In this technique, a male or 'inverse positive' of the character to be stamped is created and then applied to the substrate under sudden pressure (often by hand). An indented character is left behind. This method is commonly used on metal substrates, particularly in motor vehicle manufacturing industry.

- ***Rolling.*** A similar process to die stamping. In this case, the characters to be stamped are applied to the substrate with a slower, steadier pressure.

- ***Scribe marking.*** A combination between cold spinning and engraving method, producing only microchips due to the micromachining cutting. Scribe markers for vehicle identification numbers (VIN) are often mounted on a robot arm.

- ***Embossing.*** Involves a technique similar to die stamping or rolling but is used on thin metal plates to produce a raised print appearance. The die is pushed on to the plate from behind.

- ***Pin stamping.*** Small pins are used to form individual dots on the substrate, using an impact process. By arranging these dots into the appropriate pattern, the requisite characters are formed. The process is analogous to dot matrix computer printing.

- ***Roll marking.*** Cold presswork used to mark the periphery of cylindrical or solid circular work pieces. Shock absorbers and break disks are marked in roll marking stations.

- ***Type wheel marking.*** Cold presswork method, where vehicle markings are performed in a hydraulic press with preprogrammed or with computer-controlled type wheels.

- ***Engraving.*** The substrate is cut away by a tiny spinning head or similar, leaving marks which form the serial number. This method is particularly common in plastic substrate or where numbers are being applied by a consumer.

- ***Laser etching.*** A technique that is coming into widespread favor, this effectively involves burning the serial numbers into the substrate by applying an industrial laser, such as carbon dioxide laser.

REMOVAL METHODS OF IDENTIFICATION MARKS

Generally, methods used to remove identification marks involve a physical abrasion of the substrate until the marks are no longer visible. Methods to do this include filing, grinding (usually with an electric or air powered angle grinder), sanding with sand paper or emery paper or scraping with a sharp implement, especially on plastic substrates.

Besides removing, identification marks can also be obliterated so that they are no longer decipherable. This includes peening and center punching or cold chisel. Criminals always take steps to remove or obliterate the identification numbers so that they can no longer be recognized nor be proved to be stolen (Wilson, P.B, 1979).

- ***Filing and grinding.*** This method is done by simply using hand filling or grinding with a high speed carborundum grinding wheel, usually followed by polishing and then over stamping with a new number.

- ***Erasing using emery or sand paper.*** This method is utilized by applying emery or sand paper of different grades on the metal surface until the marks are not visible.

- ***Center punching.*** This method is used to fully obliterate the marks. It is done by punching with a pointed punch on the surface in order to hide or distort the whole number surface. It is usually extremely difficult to interpret any restored number because this method will alter the crystalline structure of the metal. Any restoration performed will restore the center punching marks as well as the serial number.

- ***Welding.*** This technique is done by heating the surface until the metal flows with either an oxy-acetylene or an arc welder.

- ***Drilling.*** The numbers and the surrounding metal will be completely removed using a drill. The hole will then filled up with lead solder or weld material or other filler in order to hide the distortion left.

PRINCIPLES OF DEFORMATION AND RESTORATION

A study of the behavior of the metal and plastics during deformation is necessary to understand the fundamentals of restoration process (Pohl, M. et al, 1995). It is important to understand that restoration of erased identification mark is only possible if the material onto which they are present still contains physical deformation due to their original presence.

When a metal is stamped, engraved or punched, the metal surface as well as structure beneath the metal is deformed. The latter deformation is not visible to the naked eye and can be classified into two main deformation zones; *elastic* (nonpermanent) and the *plastic* (permanent). If the zone of plastic deformation is still present after the obliteration, it should be possible to restore the serial number.

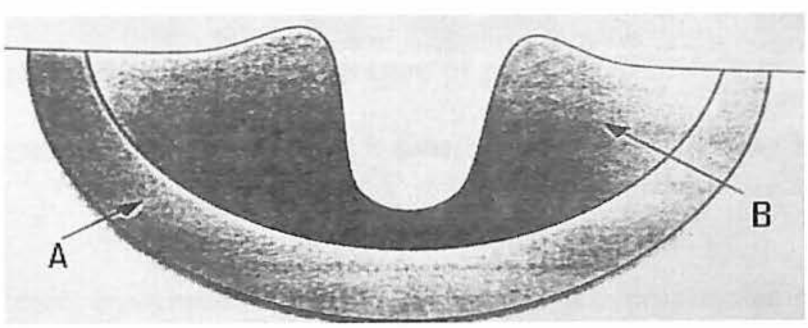

Figure 1: Deformation below the metal surface; A is zone of elastic deformation and B is zone of plastic deformation (Katterwe H., 2006).

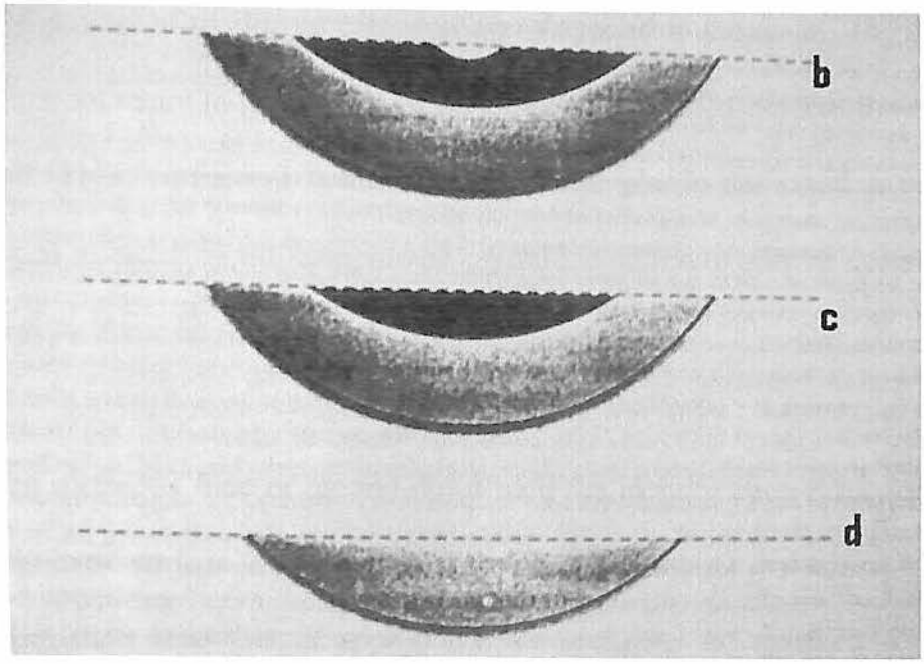

Figure 2: Different level of erasure of identification marks on a metal surface (Katterwe H., 2006).

Figure 2 shows an example where the criminal would partially grind or sand the identification marks. This partial obliteration might appear complete to the untrained eye, as some of the material resulting from the grinding accumulates in the small hole and covers it (Figure 2, b). The marks should be visible by cleaning of the surface. If the marks are erased until it is not visible to the naked eyes, restoration is still possible because plastic deformation zone is still there (Figure 2, c). If the criminal pushes the obliteration further, which is complete erasure of plastic deformation zone (Figure 2, d), restoration of erased identification marks is usually impossible (Katterwe H., 2006).

Microscopic examination reveals that metals are polycrystalline in structure (Katterwe H., 2006). They consist of irregularly shaped crystal or grains, which form when molten metal cools to the point of solidification. Between the grains are interlocking regions known as grain boundaries. The grains are deformed when a stress, whether in a manner of tension or compression, is applied to the metal. The structure of the metal does not return to its original shape if the stress applied exceeds the elastic limit of the metal. Thus, permanent deformation or rather plastic deformation occurs. The depth of metal affected by the compressed crystalline structure will be depending upon the metal and the force applied to the surface of the metal.

If the surface is filed or ground down until the identification mark has just been removed, the new surface will still contain an area of altered crystalline structure or plastic deformation zone that, if appropriately treated, can be revealed. This area of plastic deformation will conform to the outline of the obliterated identification mark. This erased mark can be revealed by the action of a suitable etching reagent which will show the change in crystalline structure from a compressed to a non-compressed area (Heard, B.J., 1997).

REVIEW OF LITERATURE

There are several studies that have been conducted regarding the restoration of erased identification number particularly on metal surface. Those studies have been done to understand more about the theories, principles and methods to successfully restore the erased identification mark on metal surface.

Nikolls L. C. (1956) has described some of the methods used to place markings on items such as casting, engraving and punching. Besides, he also listed several techniques to restore the obliterated serial numbers on different surfaces including iron, stainless steel, cast steel, aluminium alloys, wood, plastics and leather. He suggested that the depth of distorted or altered material during stamping is very small, which may not exceed 1 millimeter in metal, but may be more in wood and less in leather. Unevenness of the depth of the impression occurs from letter to letter, if the punching is done using hand.

Treptow R. (1978) also discussed crystalline structure of metal that are comprised of small units called grains that are irregular in shape. The size of these grains is regulated by the rate at which the metal is cooled after it has been heated and formed. Treptow studied that between the grains are interlocking regions known as grain boundaries and the strength of these boundaries relates directly to the strength of the metal surface and its ability to resist stress. Treptow, Polk and Giessen (1978, 1989) devoted a significant portion of their writings to explaining the metallurgical effects of stress to metal.

Wilson P.B. (1979) reviewed the metallurgy and the principles behind the restoration and reported some successful cases of the restoration of erased stamped marks using chemical etching.

Turley D. M. (1987) studied the relation between the depth of stamp mark and the depth to which the stamp mark can be restored using etching and magnetic techniques. He found that the depth of restoration increased with increasing depth of the stamp mark. The depth of restoration was proportionately greater for stamp marks of small depth. He also studied the ratio of the depth of restoration to the depth of stamp marks and noticed that for stamp marks of small depth (0.1mm) the ratio was 4 to 5, while for large depth of stamp mark (0.4mm) the ratio was about 2. He found that increased stamp mark size also resulted in an increase in the depth of restoration.

Polk D. E. and Giessen B. C. (1989) have discussed in detail the metallurgical background. They have described that the metal consists of polycrystalline structure or grains which, if a force applied on them, will undergo elastic and plastic deformation. The deformation of a metal after force is applied is described using dislocation model. Dislocations are not just a useful model, but they can actually be observed under high magnification using a transmission electron microscope. Those studies have shown that metals contain large numbers of intertwined dislocations and that the dislocation density has increased after plastic flow. The amount of plastic flow and the depth to which the plastic region extends below the indentation depend upon the shape of the die and depth of indentation. Blunter die will produce plastic flow to a greater depth than sharper, V-shaped dies. Etching method for serial number recovery has become well known to metallurgist as dislocation or the boundary between grains or from a region of localized elastic stress is electrochemically active than the remainder of the substance. Thus, it can be made to dissolve preferentially in a suitable acidic solution.

Susan L. M. (1993) used heat to recover obliterated serial number in her work at Scientific Section of Queensland Police Service. The cleaned surface of metal is treated with direct heat of 3500°C flame from a welding oxy-acetylene torch until the obliterated number is visible.

Katterwe H. (1993) has studied methods for serial number restoration in metals and polymers. An erased polymer can be restored by heating it to the glass temperature as the molecule chains are forced back into their originally, statistically coiled deformation. Katterwe also found that good results were obtained by using clove powder (Eugenol) as swelling agent in ABS plastic material. Markings in transparent polymers such as polymethylmethacrylate or polycarbonate can be made visible between crossed polars, since orientated macromolecules exhibit birefringence.

Heard B. J. (1997) has reviewed the theory behind number restoration and several methods used for removal of serial numbers which are filing or grinding, peening, over stamping, center punching, drilling and welding. He also stated that drilling and welding will permanently remove all recoverable traces of the original number. He studied several methods for restoration of erased number including chemical etching, magnetic particle technique, electrolytic technique, ultrasonic cavitation technique and heat etching. He also listed some reagents which have been useful in chemical etching restoration for different surfaces such as iron and steel, aluminium and aluminium alloys, zinc and zinc/ aluminium alloys and brass. He found that the most simple and most efficient technique was chemical etching, which does not require any expensive or bulky equipment, was quick, simple and the results can be easily photographed.

Brown E. W. (2001) has found a technique to provide a good recovery of obliterated serial number on the aluminium alloy plate of Ruger P-85 pistol using acidic ferric chloride reagent. The ground aluminium plate was polished using water and fine 600-grit paper. A small pool of an acidic ferric chloride chemical etching reagent was added to the surface of polished metal. The reagent was added drop wise using saturated cotton tipped swab and the tip of the swab was lightly pressed directly to the frame and removed. No wiping was done and the reagent was allowed to effervesce for 1 to 2 minutes. Reagent was removed by spraying with distilled water and the process was repeated until the erased numbers were visible. He found that holding the frame against a light background and tilting the frame to an oblique angle to observer seemed to help increase the contrast between the darker lettering and the lighter metal of the frame.

Katterwe H. (2006) described several marking methods used in the automotive industry which are die stamping, stylus/ pin marking, roll marking, type wheel marking, engraving, scribe marking and laser beam marking. He also discussed the principle of deformation and restoration on metals and plastics and determined that restoration is not possible if plastic deformation zone is fully erased. He suggested several destructive and non-destructive restoration techniques for metals and plastics. He added that chemical etching on aluminium alloys can be made by using dilute sodium hydroxide which consists of 10g sodium hydroxide (NaOH) and 90g water.

Azlan M. et al (2006) has studied erased engraved marks on steel plates. They conducted experiments to restore erased engraved marks on steel plates by using chemical etching method. They suggested that the reagent consisting of 5g of cuprum sulphate ($CuSO_4$), 60ml hydrochloric acid (HCl), 30ml of ammonium hydroxide (NH_3OH) and 60ml water was the most sensitive. The reagent was able to restore engraved marks which had been erased 0.04mm below the depth of engraving (0.03mm). They also found that depth of restoration of erased engraved marks on the steel plate is reduced, if the erased mark is erased and over-engraved by another marks. The reagent used also successfully restore engraved marks which have been obliterated using center punching.

Thus the above studies have contributed much to understand the number recovery process. However, it was noticed that much information is not available in literature regarding the depth to which erased engraved marks on metal, especially aluminium surfaces can be revealed. Since aluminium is an important metal used in parts of automobiles, aircraft and guns, it was decided to probe the etching techniques on aluminium surfaces.

OBJECTIVE OF THE STUDY

Engraved identification marks have been used increasingly in chassis and engine numbers of cars and guns (Klees G. S., 2002). Aluminium alloys have also been used as a main component of motorcycle engine and serial number plate on guns as stated earlier. Therefore, this research is concerned with restoration of erased engraved marks on aluminium surfaces with the following objective:

1. To identify the most sensitive reagent that can restore erased engraved marks on aluminium surfaces. This is determined by finding the maximum erasure depth through which the original engraved marks are recovered by the reagent. Conversely, the experiments would also establish the levels of erasure depths to which engraved marks could be recovered.

METHODOLOGY

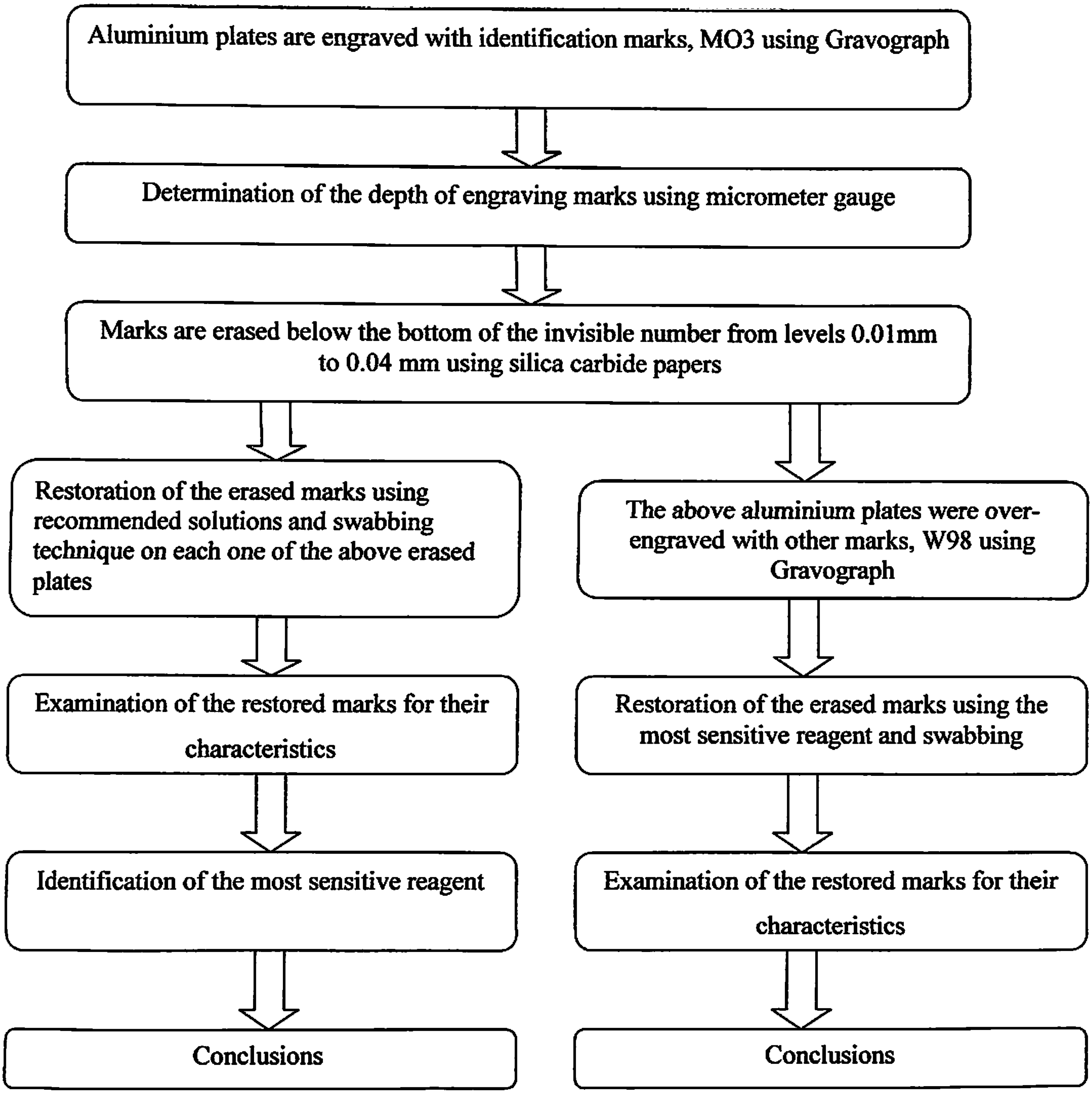

Chart 1: Flow chart showing step-by-step process in the experiments to identify the most sensitive reagent to restore the erased engraved marks on aluminium surfaces.

A series of experiments was designed in order to achieve the objective of this study. The experiments consisted of identifying the most sensitive reagent to restore the erased engraved marks on aluminium surface. This was done by determining the maximum depth below the depth of the engraving which the reagent is capable of restoring.

Engraved Plates

Several aluminium plates of dimension of 10.5 cm long, 2.5 cm wide and 0.61 mm thick were selected. Those plates were then engraved with a combination of alpha-numeric characters, MO3 using a computerized mechanical machine called Gravograph (Gravograph-UNICA TX, USA). The machine (Figure 3) was able to make reproducible engraving marks on each plate. The marks MO3 were chosen, as they contain both curved and straight surface. Those plates were labeled appropriately as they will be erased to different depths below the depth of engraving and later treated with different etching solutions.

Figure 3: A Gravograph machine.

Figure 4: An aluminium plate with alpha-numeric characters MO3.

Erasure of engraving

The depth of the engraving on the plates was measured using micrometer screw gauge. In order to do this, the marks MO3 were erased using graded sand paper which consisted of coarse grade (P100), medium grade (P150) and fine grade (P320). Prior to erasure, acetone was applied to the surface to remove debris and then measurement was taken. This was the original thickness of the plate which was determined to vary between 0.60 mm to 0.61 mm. Some marks were made by using blue permanent pen marker just above the engraved marks to give the estimated location of the original marks once they are erased. Later, the marks were erased until the visible engraving marks were not present anymore. Acetone was applied to remove the debris. Measurement of the plate was taken again. The difference in measurement between the original plate and measurement after erasure until the marks were just not visible would be the depth of engraving. The depth of engraving of those plates was determined to vary between 0.02 mm and 0.03 mm. (The variation might be due to the error of judgment in determining the exact depth at which the marks were erased to become invisible.)

Several plates were then erased to different depths below the depth of engraving. This was done as these plates are going to be treated with different etching solutions. The solution which can restore the maximum erasure depth would be considered the most sensitive solution. The following five aluminium plates were prepared:

1. Plate 1: removal of visible engraving with erasure depth of the depth of engraving (which vary between 0.02 mm to 0.03 mm). This plate is labeled as **(a).**
2. Plate 2: removal of the visible engraving, plus erasure down to a depth of 0.01 mm below the depth of engraving. This plate is labeled as **(b).**
3. Plate 3: removal of the visible engraving, plus erasure down to a depth of 0.02 mm below the depth of engraving. This plate is labeled as **(c).**
4. Plate 4: removal of the visible engraving, plus erasure down to a depth of 0.03 mm below the depth of engraving. This plate is labeled as **(d).**
5. Plate 5: removal of the visible engraving, plus erasure down to a depth of 0.04 mm below the depth of engraving. This plate is labeled as **(e).**

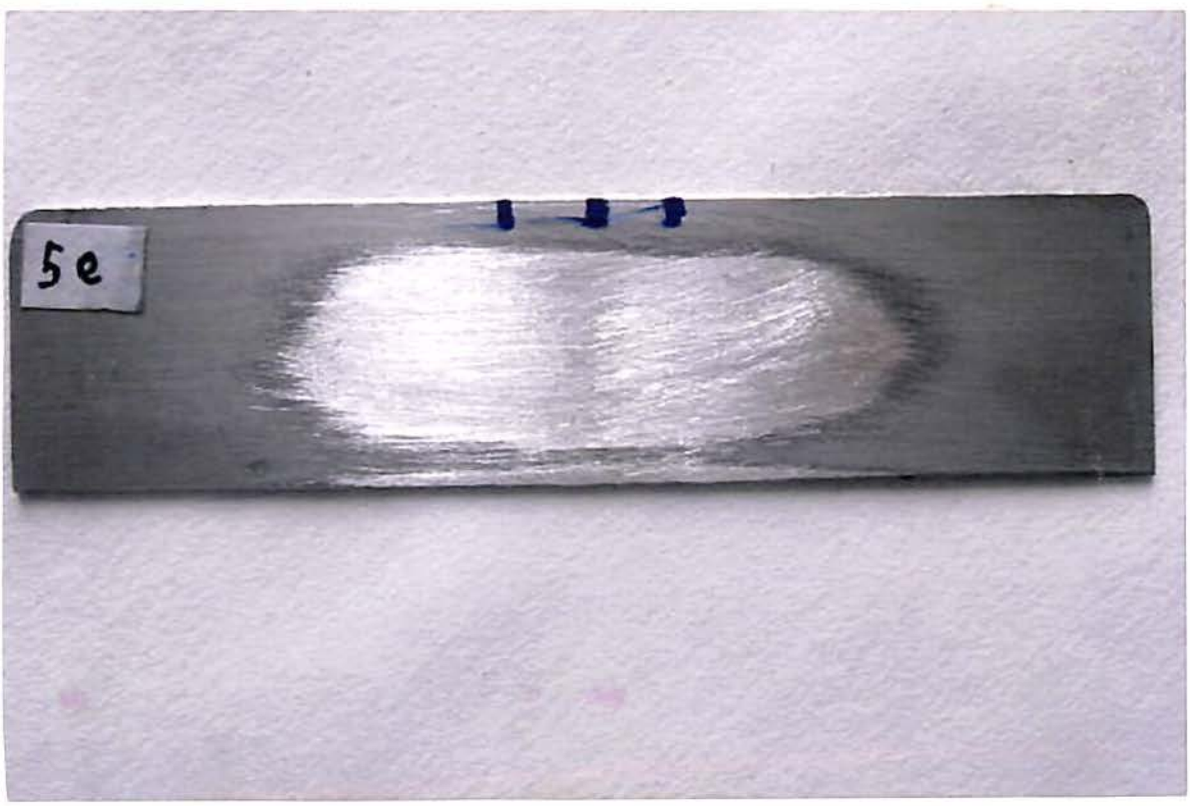

Figure 5: The plate after erasure of the engraved marks.

Selection of etching solutions

The metallographic reagents that were recommended by several workers for the restoration on aluminium surface are given in Table 1. These etchants were applied on the aluminium surfaces to bring back the original engraved marks.

Assigned name	Reagents	Composition	Recommended by
Etching solution 1 (Dilute Sodium Hydroxide)	1. Sodium hydroxide 2. Water	10 g 90 g	Siegel J.A. et al, 2000 Katterwe H., 2006
Etching solution 2 (Hume-Rothery's Solution)	1. Cupric chloride 2. Hydrochloric acid 3. Water	200 g 5 mL 100 mL	Nickolls L.C. 1956, Heard B.J.,1997, Siegel J.A. et al, 2000
Etching solution 3 (Dilute nitric acid)	1. Nitric acid 2. Water	25 mL 75 mL	Jackson R.L., 1950 Siegel J.A. et al, 2000
Etching solution 4 (Alternating acid and alkali)	1. Sodium hydroxide 2. Nitric acid	10% 10%	Siegel J.A. et al, 2000
Etching solution 5	1. Hydrochloric acid 2. Sodium hydroxide	60% 40%	Azari , 2006
Etching solution 6	1. Ferric chloride ($FeCl_3$) 2. HCl 3. Water	25 g 25 mL 100 mL	Brown E.W., 2001

Table 1: Etching solutions used to restore erased engraved marks on aluminium surfaces.

Restoration procedures

The restoration was done by swabbing technique in which cotton bud was dipped in the etching solution and applied on to the aluminium surfaces in which the engraving marks were erased to a different depth. The etchant was applied by swabbing on the entire erased surface of the aluminium plate evenly and constantly with a gentle movement and also at the same force all the time.

Figure 6: Swabbing of etching solution in the area of the erased marks by cotton bud.

In order to conclude that an etching solution was the most sensitive, the following factors were considered; clarity and appearance of the recovered numbers. Time consumed to reveal the erased engraved marks was also taken as an additional criteria, even though it was not that important. Therefore, once the etchant was swabbed onto the metal surface, time needed was recorded until the number could clearly be visualized, but in case of unsuccessful restoration, certain time limit was decided for the swabbing process to be carried out. For this study, it was decided that the time limit is one hour, which meant that if swabbing was done more than that time and the number did not appear by then, it was considered that the etchant was not effective. A magnifier was used to observe the restored marks. The plates were observed at different angles but only at certain angles, the marks could be seen more clearly. A conclusion was then derived from the result obtained from the experiments.

A few experiments were also conducted to determine whether the most sensitive reagent identified in the previous experiments could restore the marks that have been erased and over-engraved with numbers. For this, five aluminium plates were engraved with original numbers, MO3, erased to different depth and over-engraved with numbers W98. The most sensitive reagent was applied to the above plates by swabbing on the aluminium surface. The purpose of the experiment was to find out whether the additional deformation introduced by over-engraving has any effect on the recovery of engraved marks.

RESULTS AND DISCUSSION

The experiments conducted in order to determine the sensitivity and effectiveness of some recommended etching solutions on the erased engraved marks on aluminium plates have provided some fundamental information.

1. *Etching solution 1*

The etchant known as diluted sodium hydroxide solution contained 10 g sodium hydroxide (NaOH) and 90 g of water. The clarity of the restored marks could be classified as poor. The marks could only bee seen at an oblique angle of illumination and they appeared faintly. This solution could only restore marks which had been erased up to the depth of engraving. Immersion method which had been proposed by Brown E. W. (2001) was also used in order to see the marks clearer. A wall was built around the marks and a pool of etching solution 1 was dipped on the aluminium plate and left overnight. The plate was observed the next day but the plate became corroded and the marks could not be seen as much corrosion took place.

2. *Etching solution 2*

This etching solution also known as Hume-Rothery's solution consisted of 200 g cupric chloride ($CuCl_3$), 5 ml hydrochloric acid (HCl) and 1000 ml of water. This etchant could not restore the erased marks even after one-and-half hour of etching. Immersion method was also applied. However, the plate became corroded and could not reveal any of the marks.

3. Etching solution 3

This etchant consists of 25 ml nitric acid (HNO_3) and 75 ml of water. This diluted nitric acid solution could only restore the marks which had been erased up to the depth of the engraving. The clarity of the restored marks was very poor and only some portion of the marks appeared very faintly and also could only be seen at the right angle and with sufficient amount of light.

4. Etching solution 4

This etchant consists of two different solutions: 10% sodium hydroxide (NaOH) and 10% nitric acid (HNO_3). Those solutions were applied alternately and acetone was applied in between those solutions. Each solution was applied on the aluminium surface for three minutes. This solution could only restore the erased mark up to the depth of engraving. The restored marks appeared faintly and the quality can be classified as poor.

5. Etching solution 5

This etchant consists of two different solutions; 60% hydrochloric acid (HCl) and 40% sodium hydroxide (NaOH). Those solutions were applied alternately; three minutes for each solution until the erased marks were retrieved. Acetone was applied in between those solutions. The experiment as started by applying 60% of HCl for three minutes followed by swabbing with 40% NaOH for almost the same time. This solution was quite sensitive, as it could restore the erased marks, which was erased 0.04 mm below the depth of engraving. The clarity of the restored marks was excellent, as the marks could be visualized even without looking it at certain angle and sufficient lighting (Figure 7b and 7c). However, the clarity was excellent until an erasure depth was 0.03 mm but decreased on the plate 0.04 mm below the depth of engraving. It became faint but still readable (Figure 7d). The erosion rates of both the solutions were high particularly the 60% HCl. This may explain the less restoration time for the erased marks.

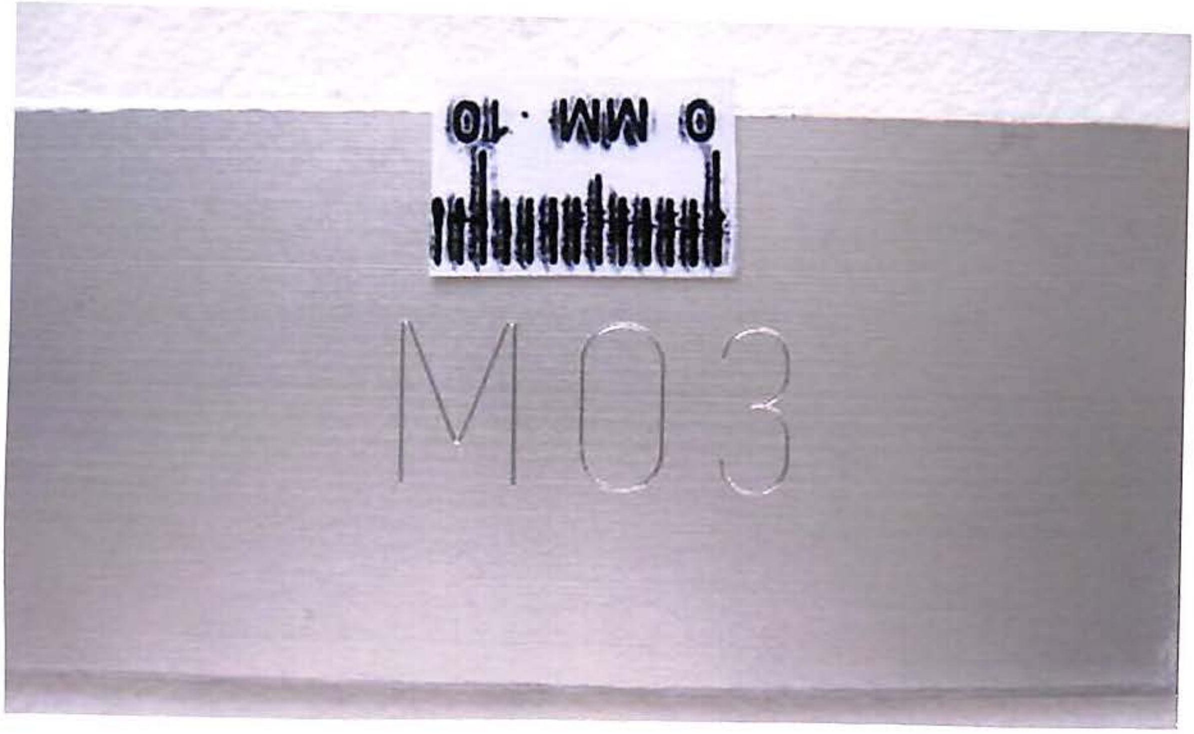

Figure 7a: Photograph of original engraving marks.

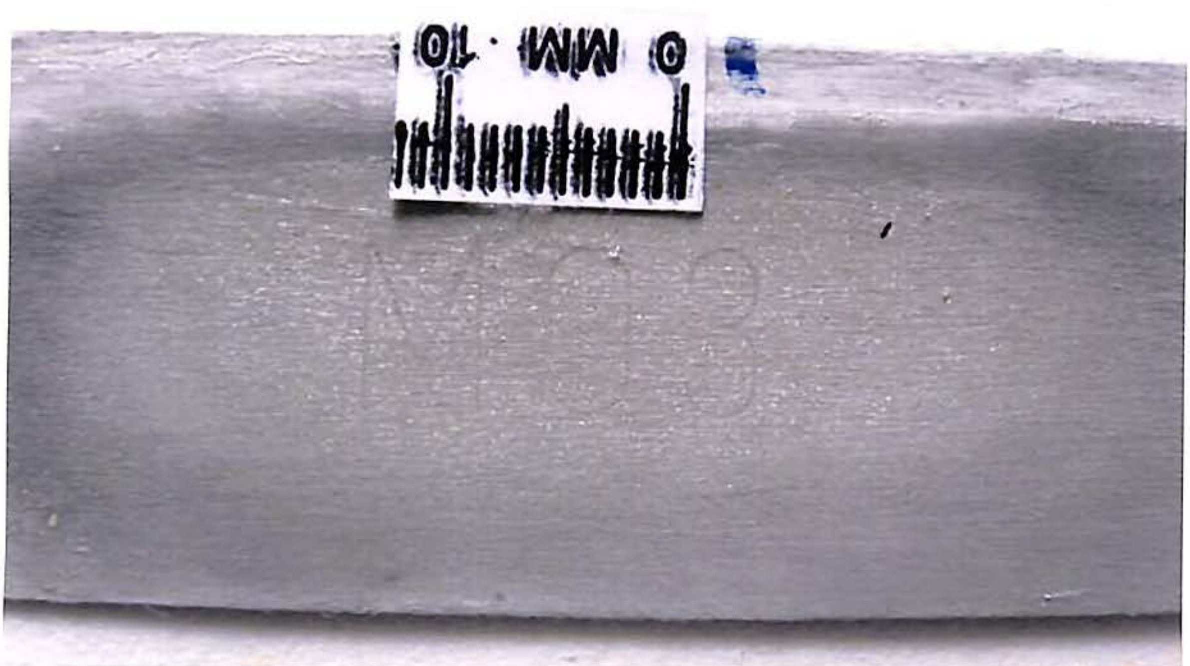

Figure 7b: Photograph of a restored number using 60% hydrochloric acid (HCl) and 40% sodium hydroxide (NaOH), at an erasure to a depth of 0.01 mm below the depth of engraving.

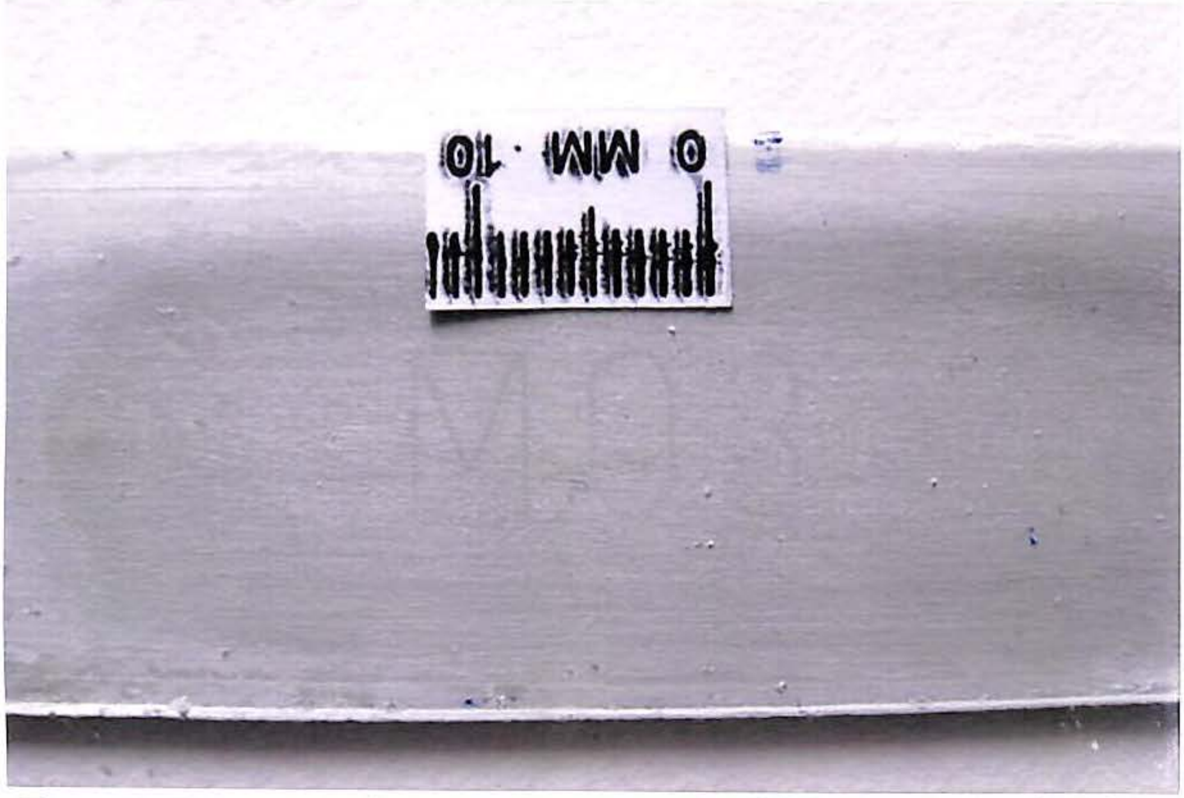

Figure 7c: Photograph of a restored number using 60% hydrochloric acid (HCl) and 40% sodium hydroxide (NaOH) at an erasure depth of 0.03 mm below the depth of engraving.

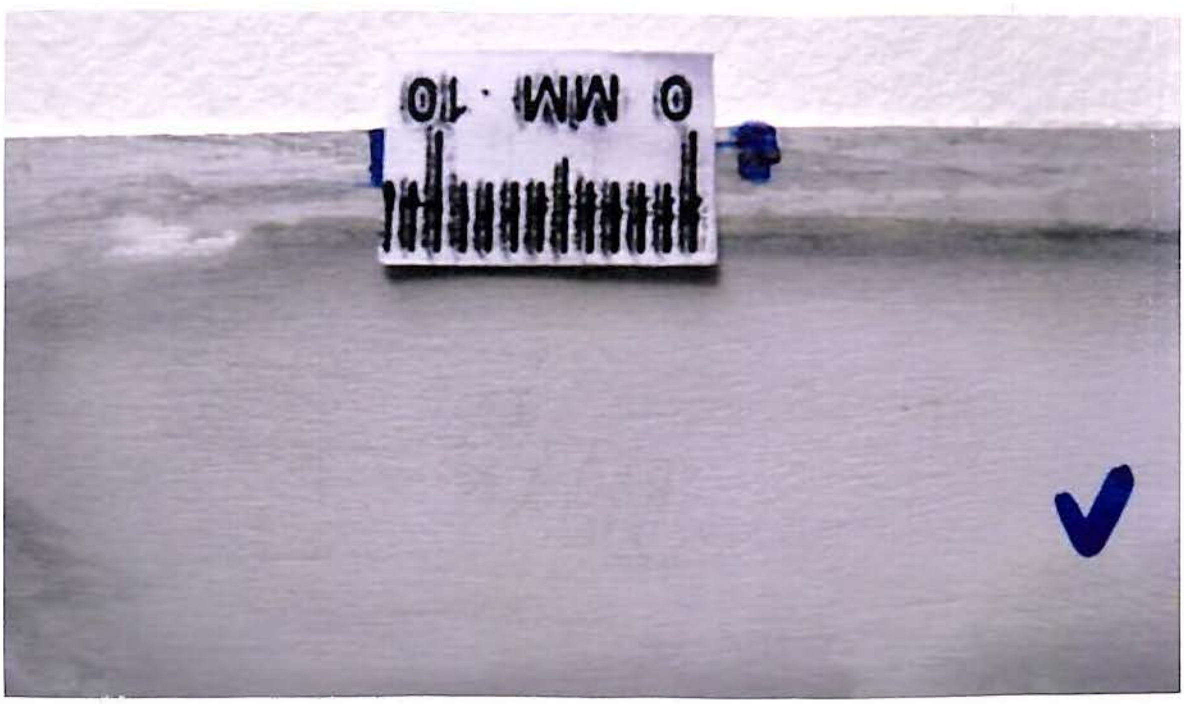

Figure 7d: Photograph of a restored number using 60% hydrochloric acid (HCl) and 40% sodium hydroxide (NaOH) at an erasure to a depth of 0.04 mm below the depth of engraving.

6. Etching solution 6

This etchant consists of 25 g of ferric chloride ($FeCl_3$), 25 ml of hydrochloric acid (HCl) and 100 ml of water. This solution could restore the erased marks up to the plate, which was erased 0.04 mm below the depth of the engraving, the same depth as the etching solution 5 revealed. The clarity of the restored marks on the first plate (erased until the visible engraving is just removed) was good. However, the marks could only be seen at certain angle with less amount of lighting. Large amount of lighting was likely to hide the number. The clarity of the restored marks decreased as the restoration proceeded to the plate which had been erased 0.04 mm below the depth of engraving. The marks appeared very faintly.

The experiments thus revealed that both the etching solutions 5 and 6 were able to restore the erased engraved marks up to the plate which was erased 0.04 mm below the depth of engraving. Etching solution 5, which consisted of two different solutions; 60% hydrochloric acid (HCl) and 40% sodium hydroxide (NaOH) was determined to have better sensitivity than etching solution 6 (acidified ferric chloride) because of the excellent clarity of the restored marks. Etching solution 5 had given excellent restoration for the erased marks. In addition, restoration of the erased marks using etching solution 5 also required lesser time. Table 2 summarizes the relative sensitivity and efficacy of different reagents in restoring erased engraved marks on aluminium surfaces.

Etchant	Depth below the bottom of the engraving through which restoration was possible(mm)	Application method	Time for recovery of the marks (minutes)	Characteristics of the restored marks
Etching solution 1 - 10 g sodium hydroxide - 90 g water	0.00 (erasure up to the depth of engraving)	Swabbing with cotton bud and immersion technique	13-60	Faint
Etching solution 2 - 200 g cupric chloride - 5 ml hydrochloric acid - 1000 ml water	None	Swabbing with cotton bud and immersion technique	-	-
Etching solution 3 - 25 ml nitric acid - 75 ml water	0.00 (erasure up to the depth of engraving)	Swabbing with cotton bud	50-85	Very faint
Etching solution 4 - 10% sodium hydroxide - 10% nitric acid	0.00 (erasure up to the depth of engraving)	Swabbing with cotton bud	21-60	Faint
Etching solution 5 - 60% hydrochloric acid - 40% sodium hydroxide	0.04	Swabbing with cotton bud	3-60	Quite distinct till the depth of 0.03 mm. Became less distinct at 0.04 mm but still recoverable at the depth.
Etching solution 6 - 25 g ferric chloride - 25 ml hydrochloric acid - 1000 ml of water	0.04	Swabbing with cotton bud	17-60	Quite distinct till the depth of 0.03 mm. Became less distinct at 0.04 mm but still recoverable at the depth.

Table 2: Sensitivity of different etchants in restoring erased engraved marks on aluminium surfaces.

There were several things that should be noted during these experiments. Observation of the restored mark could be made easier by looking it at certain angle or particularly at an oblique angle. The use of glass magnifier (x2) in the observation had been found to be very useful. After restoration, the restored marks were preserved by applying grease on it. Photographs were taken to show the results of the experiment.

Those plates in which the engravings were erased to different depths and over-engraved were treated using the most sensitive reagent, 60% hydrochloric acid (HCl) and 40% sodium hydroxide ($NaOH$). For the plate with erasure depth of engraving, the restored engraved marks were excellent after seven minutes of etching. The next plate which erasure was 0.01 mm below the depth of engraving, restoration was also excellent (Figure 8b). The restored engraved marks, MO3 were clearly visible underneath the over engraved marks, W98. For the plate which erasure was 0.02 mm below the depth of engraving, restoration could only reveal the original marks faintly but distinct (Figure 8c). However, the clarity of the restored mark decreased for the plate erased 0.03 mm deep (Figure 8d). For the plate erased 0.04 mm below the depth of engraving, restoration was very poor. The restored marks appeared very faintly and hardly can be differentiated from the over engraved marks. Table 3 summarizes the sensitivity of the reagent in restoring erased engraved marks on aluminium surface which has been engraved with other engraved marks.

These observations are found to be similar of the previous findings of Azlan et al (2006) who did researches on steel surface. They reported that the depth of restoration of engraved marks decreased, if the marks once were erased and later over engraved with other engraved marks.

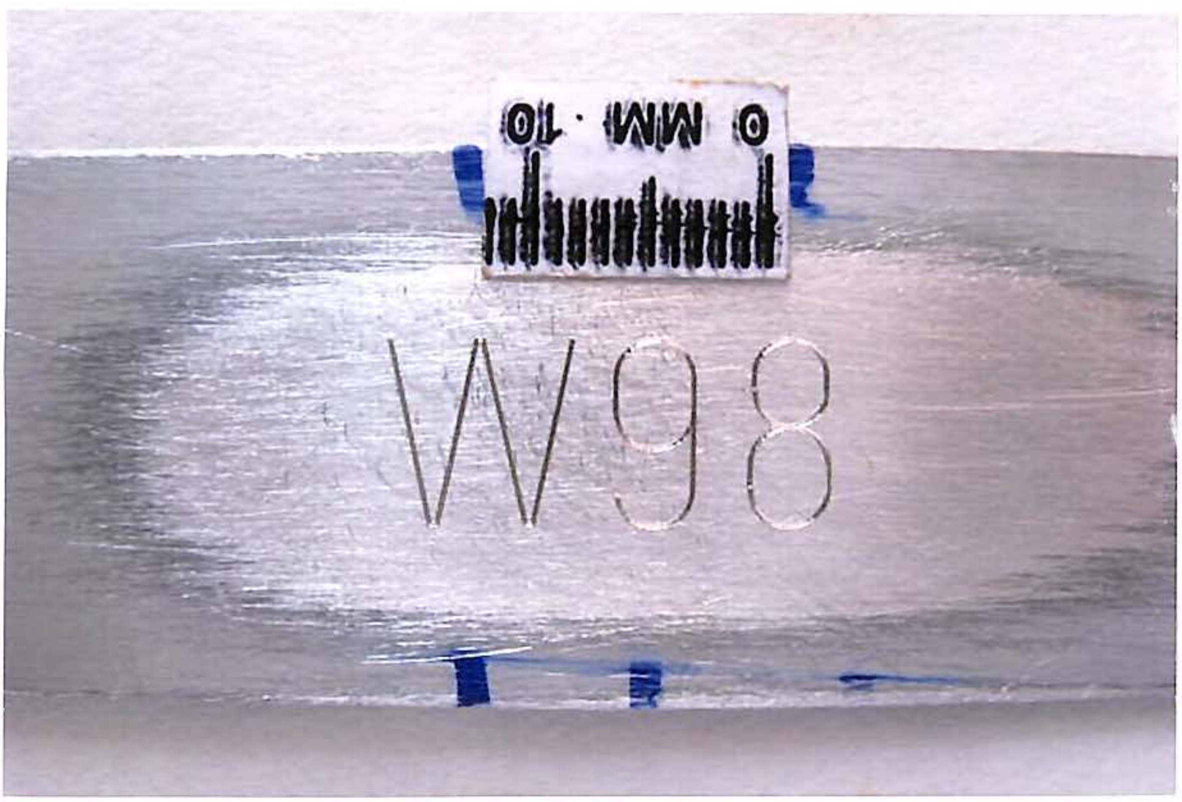

Figure 8a: Photograph of aluminium plate which has been erased 0.01 mm below the depth of engraving and over-engraved with another mark, W98.

Figure 8b: Restoration of the original mark (MO3) on the plate which was erased 0.01 mm below the depth of engraving and over-engraved with W98 mark.

Figure 8c: Restoration of the original mark (MO3) on the plate which was erased 0.02 mm below the depth of engraving and over-engraved with another mark W98.

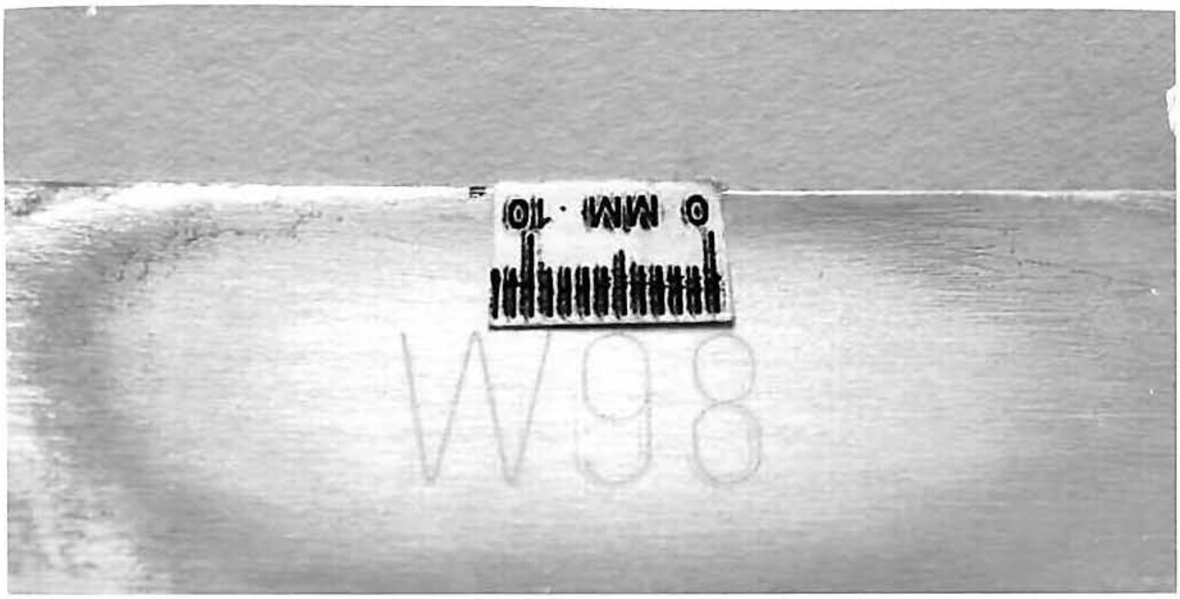

Figure 8d: Restoration of the original mark (MO3) on the plate which was erased 0.03 mm below the depth of engraving and over-engraved with another mark W98.

Depth of erasure (mm)	Etchant	Application method	Number restored ?	Clarity	Observation
0.00 (erasure up to the depth of engraving)	Etching solution 5 - 60% hydrochloric acid - 40% sodium hydroxide	Swabbing with cotton bud	Yes	Excellent	- after 7 minutes, the marks could be clearly seen - restoration was excellent
0.01			Yes	Excellent	- after 3 minutes, the erased marks were developing - after 6 minutes, the marks were improving and can be observed at certain angle - after 8 minutes, the marks could be seen clearly
0.02			Yes	Poor	- after 3 minutes, some stroke of the erased marks appeared faintly - after 9 minutes, the marks appeared faintly but distinct - further restoration for 1 hour was not improving the appearance of the marks
0.03			Yes	Very poor	- after 12 minutes, the marks appeared very faintly - after 1 hour, the clarity of the marks was not improving, so the experiment was stopped

Table 3: The table shows the sensitivity of 60% hydrochloric acid (HCl) and 40% sodium hydroxide (NaOH) in restoring erased engraved marks, MO3 on aluminium surface which has been over-engraved with other marks, W98.

CONCLUSION

The results of the experiments have shown that there are two solutions that are sensitive to restore erased engraved marks on aluminium surfaces: (1) 60% hydrochloric acid (HCl) and 40% sodium hydroxide ($NaOH$) and (2) acidified ferric chloride solution. However the better of the two etching solution for restoring the erased engraved marks on aluminium surface is 60% hydrochloric acid (HCl) and 40% sodium hydroxide ($NaOH$).

The depth of restoration of the erased engraved marks on aluminium surfaces in this experiment is determined to be 0.04 mm below the depth of engraving. This indicates that, after the visible indentation of engraved marks has been erased, restoration is still possible up to 0.04 mm below the indentation. Thus, it can be concluded that the depth of distortion of aluminium grain or plastic deformity produced by the engraving extended to 0.04 mm beneath the aluminium surface; for an engraving depth of 0.03 mm.

However, the depth of restoration on the aluminium surface decreased slightly when the original engraved marks were erased and over engraved with other marks and treated with the most sensitive solution, 60% hydrochloric acid (HCl) and 40% sodium hydroxide ($NaOH$). Based on the experiment, the restoration was only possible up to 0.03 mm below the depth of engraving. This indicated that the over engraving marks has interfered or changed the plastic deformation beneath the aluminium surface, which made restoration beyond that particular depth not possible. The results reported here are similar to those obtained for restoring engraved marks on steel surfaces (Azlan et al, 2006).

The results of this study could be used by other researchers as a helpful material for the initiation of further research involving the engraved marks on aluminium surfaces in order to understand more about the principles and also enhancement of the procedure.

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